भारतीय मानक
Indian Standard

IS 17128 (Part 2) : 2019

स्वचल वाहन — वाहन गतिकी परीक्षण पद्धतियाँ

भाग 2 वाहन स्थिरता एवं नियंत्रण क्षमता के लिए स्थिर अवस्था परीक्षण पद्धति — खुला लूप एवं बंद लूप परीक्षण

Automotive Vehicles — Vehicle Dynamics Test Methods

Part 2 Steady-State Test Procedure for Vehicle Stability and Controllability — Open-Loop and Closed Loop Test

ICS 43.020

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Automotive Braking and Steering System, Vehicle Testing and Performance Evaluation Sectional Committee, TED 04

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Automotive Braking and Steering System, Vehicle Testing and Performance Evaluation Sectional Committee had been approved by the Transport Engineering Division Council.

The dynamic behavior of a road vehicle is a most important part of vehicle safety. Any given vehicle, together with its driver and the prevailing environment, forms a unique closed-loop system. The task of evaluating dynamic behavior is therefore very difficult since there is a significant interaction between these driver-vehicle-environment elements, each of which is complex in itself. A complete and accurate description of the behavior of the road vehicle must necessarily involve information obtained from a number of tests of different types. Since they quantify only a small part of the complete vehicle handling characteristics, the results of these tests can only be considered significant for a correspondingly small part of the overall dynamic behavior.

Less data is acquired to obtain relationship between overall vehicle dynamic properties vs actual driving patterns. The effort is going on to do obtain correlation between accident avoidance and vehicle dynamic properties in general. Therefore, it is not possible to use this standard for regulatory purposes. Finally, test conditions and tyres have a strong influence on test results. Only vehicle dynamic properties obtained under identical test and tyre conditions are comparable.

This Indian Standard is published in five parts. The other parts in this series are:

Part 1	General test conditions
Part 3	Transient response test methods
Part 4	Ride comfort measurements
Part 5	Subjective evaluation —Vehicle ride, handling, steering and tyre evaluation

In the formulation of this standard considerable assistance has been derived from the following International Standards:

ISO 4138 : 2004 Passenger cars — Steady state circular driving behaviour — Open loop test methods

ISO 7401 : 2003 Road vehicles — Lateral transient response test methods — Open loop test methods

ISO 7975 : 2006 Passenger cars — Braking in a turn — Open loop test method

ISO/TR 8725 : 1988 Road vehicles — Transient open loop response test method with one period of sinusoidal input

ISO/TR 8726 : 1988 Road vehicles — Transient open loop response test method with pseudo-random steering input

ISO 9815 : 2003 Road vehicles — Passenger car and trailer combinations — lateral stability test

ISO 12021-1 : 1996 Road vehicles — Sensitivity to lateral wind — Part 1: Open loop test method using wind generator input

ISO 15037-1 : 2006 Road vehicles — Vehicle dynamics test methods — Part 1: General conditions for passenger cars

ISO 17288-2 : 2004 Passenger cars — Free steer behaviour — Part 2: Steering pulse open-loop test method

For the purpose of deciding whether a particular requirement of this standard is complied with the final value, observed or calculated, expressing the result of test or analysis shall be rounded off in accordance with IS 2 : 1960 ‘Rules for rounding off numerical values (*revised*)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard

Indian Standard

AUTOMOTIVE VEHICLES — VEHICLE DYNAMICS TEST METHODS

PART 2 STEADY-STATE TEST PROCEDURE FOR VEHICLE STABILITY AND CONTROLLABILITY — OPEN-LOOP AND CLOSED LOOP TEST

1 SCOPE

1.1 This Indian Standard (Part 2) defines and specifies open-loop and closed loop test methods for M1 category of vehicles as defined in IS 14272 for determining the steady-state circular driving behavior (gradients of steering wheel angle, understeer/oversteer, sideslip, roll angle, and steering wheel torque with respect to lateral acceleration). These properties are used to evaluate the vehicle stability and controllability during steady state cornering.

1.2 The manoevours included in this standard may not represent the real driving conditions but they are useful for obtaining the vehicle stability and control parameters.

NOTE — This standard provides guidelines for various test methods used to evaluate steady state vehicle properties and not for any regulatory requirements.

2 REFERENCES

The following standards contain provisions, which through reference in this text, constitute provisions of this standard. At the time of publication the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below:

IS No.	*Title*
14272 : 2011	Automotive vehicles — Types — Terminology (*first revision*)
17128-1 : 2019	Automotive vehicles — Vehicle dynamics test methods: Part 1 General test conditions

3 TERMS AND DEFINITIONS

For the purpose of this standard following terms and definitions applies.

3.1 Open Loop System

For the purpose of vehicle characterization only open loop system is used. Open loop refers to vehicle response to the particular steering inputs without any driver's feedback.

3.2 Closed Loop System

Vehicle stability and controllability is the measure of vehicle and driver combination. Driver along with the vehicle forms a closed loop system. Driver observes vehicle direction/position and accordingly corrects the input (steering, brake and accelerator) to achieve the desired path. Normally path feedback is used in closed loop system. The test results may vary based on the test driver's response to the closed loop system.

3.3 Low Speed Path Radius

Radius of the circular path transcribed by the origin of the vehicle axis system when the vehicle is operated at constant speed with a given fixed steering-wheel angle when both front and rear tyres have approximately zero slip angle and vehicle is subjected to approximately zero lateral acceleration.

4 PRINCIPLE

4.1 Test Methods

a) Open Loop:
   1) Method 1 — Constant radius test;
   2) Method 2 — Constant steering wheel angle test;
   3) Method 3 — Constant speed/variable radius test; and
   4) Method 4 — Constant speed/variable steering wheel angle.

b) Closed Loop:
   1) Method 5 — Constant radius test / variable speed / variable steering wheel angle.

All open loop four methods yield substantially similar data, but they differ in requirements for testing space, driver skill, and instrumentation. Method 1 and 3 depend upon the path-keeping ability of the driver to minimize instrumentation requirements. Method 2 and 4 use fixed steering wheel angle and measure path radius with inertial instruments. Closed loop method 5 is a continuous path tracking approach. Method 4 is

Table 1 Test Methods for Closed Loop and Open Loop

(*Clause* 6.1)

Test Method	Constant	Varied	Measured or Calculated
Open Loop Test			
Constant radius test	Radius	Speed	Steering wheel angle
Constant steering wheel angle test	Steering wheel angle	Speed	Radius
Constant speed/variable radius test	Speed	Radius	Steering wheel angle
Constant speed/variable steering wheel angle	Speed	Steering wheel angle	Radius
Closed loop test			
Constant radius test/variable speed/variable steering wheel angle	Radius	Speed, steering wheel angle	Speed, steering wheel angle

generally run at 80 to 100 km/h. Method 5 is use to acquire the vehicle limiting lateral acceleration and may cross the linear range of 0.4 g. The continuous data of method 5 also demonstrates most clearly the concepts of characteristic speed and critical speed as defined in IS 17128 (Part 1).

5 VARIABLES

5.1 Reference System

The provisions given in IS 17128 (Part 1) are applicable.

5.2 Measurement

5.2.1 Measure the following variables:

a) Longitudinal velocity (Vx);
b)Lateral acceleration (Ay); and
c) Steering-wheel angle (δ_H).

Alternatively, lateral acceleration may be determined from other motion variables (refer **9.2**).

NOTE — The method chosen to determine lateral acceleration could require the measurement of additional variables (yaw velocity, vehicle roll angle, or sideslip angle) for use in the computation.

5.2.2 The following variables should also be measured:

a) yaw velocity (dψ/dt);
b) sideslip angle (β) and/or lateral velocity (Vy);
c) longitudinal acceleration (Ax);
d) vehicle roll angle (φv); and
e) In addition, front steer angle (δ_F), rear steer angle (δ_R) and steering-wheel torque (M_H) may be measured.

6 MEASURING EQUIPMENT

6.1 Description

The variables selected for test purposes shall be measured using appropriate transducers and the data recorded on a multi-channel recording system having a time base. Typical operating ranges, and recommended maximum errors of the transducer and recording system are given in Table 1 of IS 17128 (Part 1).

6.2 Transducer Installation

The transducer installation shall comply with IS 17128 (Part 1).

6.3 Data Processing

The provisions given in **4.3** of IS 17128 (Part 1) shall apply.

6.3.1 Frequency band width in the entire measurement system including sensors and recording devices should be between 1 Hz to 20 Hz .

6.3.2 Install test sensors according to their installation instructions respectively. Install gyro at vehicle's reference point, the vertical gyro axis should be coincident or parallel to the vehicle's vertical (Z) axis.

7 TEST CONDITIONS

Test conditions shall be in accordance with Annex B of 17128 (Part 1). General data on the test vehicle shall be recorded as specified in Annex A of 17128 (Part 1).

The tyre type, brand, any special equipment on the test vehicle, any deviation in type or operating condition of components from the manufacturer's specification, the odometer reading at the beginning and end of the test, any other condition that may affect test results shall also be recorded on the test report for general data Annex B of 17128 (Part 1).

8 TEST PROCEDURE

8.1 Warm-up

The warm-up shall be carried out in accordance with **6.1** of 17128 (Part 1).

8.2 Initial Driving Condition

The conditions shall be in accordance with **6.2** of 17128 (Part 1).

8.3 General Test Descriptions

All necessary variables shall be recorded throughout the maneuver. Data shall be taken for both clockwise and anti-clockwise steering turns.

For tests utilizing discrete increments of speed, radius or steering-wheel angle, all of the test data may be taken in one turn direction followed by all the data in the other turn direction as experience has shown that this minimizes data scatter. However, to obtain more even tyre wear and reduced tyre heating, data may be taken in alternating turn directions at each test speed/radius/steering wheel angle.

The method chosen shall be noted in the section for test method specific data on the test report for test conditions Annex B of 17128 (Part 1). At a minimum; data shall be taken at increments of lateral acceleration no larger than 1 m/s^2. Increments may be reduced at higher level of acceleration based on vehicle stability.

Caution should be exercised during testing so, that tyre heating is minimized as much as possible. Tyre heating is a particular concern for test methods using continuous increase of speed with attendant long periods of data acquisition and all test methods at high levels of lateral acceleration. The tyres should be cooled to normal operating temperatures between test runs.

NOTE — Where data vary rapidly with changes in lateral acceleration, it can be useful to decrease the speed or radius or steering wheel angle change. The test should be repeated several times so that the results can be examined for repeatability and averaged.

8.4 Open Loop Test — Constant Radius Test (Method 1)

8.4.1 *Description*

This test method requires driving the test vehicle at several speed over a circular path of known radius. The standard radius of the path shall be 100 m but larger and smaller radii may be used with 40 m as the recommended lower value and 30 m as the minimum.

The directional control response characteristics are determined from data obtained while driving the vehicle at successively higher speeds on the constant radius path. This procedure can be conducted in a relatively small area. The procedure can be adapted to existing test track facilities by selecting a circle or a path of appropriate radius. Often a constant radius (in plane) road will suffice for a test facility.

The test can be run on any level constant radius path of sufficient length to attain and hold onradius steady state for at least a measurement period.

8.4.2 *Procedure*

8.4.2.1 *General*

Drive the vehicle on the chosen circular path at the lowest possible speed. Record data with the steering wheel and throttle positions fixed, so that the approximate ackermann steer angle can be recorded. Then, drive the vehicle at the next speed at which data are to be taken at step of 0.5 m/s^2 initially till vehicle reaches 3 m/s^2 and then 0.25 m/s^2 till vehicle is stable and can be controlled .

8.4.2.2 *With discrete test speeds*

Drive the vehicle onto the circle at each test speed. After attaining steady state in which the desired path radius is held within + 0.5 m the steering wheel and throttle positions shall be held constant for at least 3 s.

8.5 Open Loop Test — Constant Steering-Wheel Angle (Method 2)

8.5.1 *Description*

This test method requires driving the test vehicle at several speeds with a single selected steering-wheel angle that is held fixed. The path radius is determined by computation: from horizontal velocity and yaw velocity, or from horizontal velocity and lateral acceleration. The test exists in two variations: a series of discrete test runs, or a single continuous test run. In the first, the steering-wheel angle is applied with the vehicle travelling at discrete speeds and is maintained until steady-state conditions are reached. In the second, the steering-wheel angle is held fixed while speed is increased continuously at a slow rate, up to the limit of control. The standard steering-wheel angle shall provide a low-speed path radius of 30 m. Other radii may be used, with 20 m as the minimum. For testing to the limit of control with the standard initial condition, the path radius can increase to 100 m or more.

8.5.2 *Procedure*

8.5.2.1 *General*

First, drive the vehicle at the lowest possible speed to establish the steering-wheel angle for the selected low speed path radius. Then, drive the vehicle at successively higher speed, with the steering-wheel angle held constant or mechanically fixed within ± 1° of the angle. Run the test through desired range of lateral acceleration or until the limits of test space, vehicle speed, or vehicle stability are reached.

8.5.2.2 *With discrete test speeds*

At each selected speed the steering wheel shall be turned to the preselected steering-wheel angle and maintained until steady-state conditions including speed and throttle are attained. The steering-wheel angle and throttle position shall be held constant for at least 3 s.

8.5.2.3 *With continuous speed increase*

The steering-wheel angle shall be held constant or mechanically fixed at the pre-selected angle while the vehicle speed is steadily increased. The rate of increase of lateral acceleration should be 0.1 $m/s^2/s$. The maximum permissible rate of increase of lateral acceleration shall be 0.2 $m/s^2/s$.

8.6 Open Loop Test — Constant-Speed-Variable Radius Test (Method 3)

8.6.1 *Description*

This test method requires driving the test vehicle at one speed on circular paths of different radii, utilizing a range of steering-wheel angles. The directional-control response characteristics are determined from data plotted against lateral acceleration. This test method could require large test areas depending on the combination of speed and lateral acceleration. The discrete turn radii method requires a number of marked circles or circular segments with different radii, sufficient in number to provide 0.5 m/s^2 lateral acceleration increments at the selected speed. An adjustable steering stop should be used for maintaining constant steering-wheel angles in the discrete method.

The standard test speed is 60 km/h. If higher or lower speeds are selected, they shall be in 10 km/h increments.

8.6.2 *Procedure*

8.6.2.1 *General*

From an initial constant speed driving condition, apply steering inputs of successively increasing magnitude and hold them constant or mechanically fixed within ± 1° for 3 s after the measured vehicle motion variables reach steady state. Control the throttle in order to maintain constant speed within 3 percent throughout the test run. Run the test through desired range of lateral acceleration or until the limits of test space, vehicle speed, or vehicle stability are reached.

8.6.2.2 *With discrete turn radii*

Drive the vehicle onto the circle at the pre-selected speed. After attaining steady state, the steering wheel and throttle position shall be held constant for at least 3 s.

8.7 Open Loop Test — Constant-Speed-Variable Steering Wheel Angle (Method 4)

8.7.1 *Description*

As mentioned in **8.6.1.**

8.7.2 *Procedure*

8.7.2.1 *General*

As mentioned in **8.6.2.1**

8.7.2.2 *With discrete steering-wheel angles*

With the vehicle being driven at the pre-selected speed, apply a steering input and hold it constant for at least 3 s after the measured vehicle motion variables reach steady state. Control the throttle in order to maintain constant speed throughout the run.

> NOTE — It is possible to use the constant speed test method with discrete steering-wheel angles to extract transient response measures comparable to those obtained from the step input method of IS 17128 (Part 3) , if the steering input is applied in accordance IS 17128 (Part 3). However, since IS 17128 (Part 3) requires a fixed throttle position versus the controlled throttle position in the constant-speed test method, the resulting transient response measured might not be identical to those obtained from IS 17128 (Part 3).

8.8 Closed Loop Test — Constant Radius Test/ Variable Speed/Variable Steering Wheel Angle (Method 5)

8.8.1 *Description*

This test method requires driving the test vehicle on a circular path of known radius with varying the vehicle velocity. The standard radius of the path shall be 100 m but larger and smaller radii may be used, with 40 m as the recommended lower value and 30 m as the minimum.

The directional control response characteristics are determined from data obtained while driving the vehicle on the constant-radius path with varying the velocity. This procedure can be conducted in a relatively small area. The procedure can be adapted to existing test track facilities by selecting a circle or a path of appropriate radius. Often a constant-radius (in plane) road will suffice for a test facility.

In closed loop constant radius test the vehicle remains on the circle with a continuous, slow speed increase, during which data are taken. The forward longitudinal acceleration shall be kept constant to 0.1 m/s^2.

8.8.2 *Procedure*

8.8.2.1 *General*

Drive the vehicle on the desired circular path at the lowest possible speed. Record data with the steering wheel and throttle positions fixed, so that the approximate ackermann steer angle can be recorded.

8.8.2.2 *With continuous speed increase*

Increase the vehicle speed by forward longitudinal acceleration of 0.1 m/s^2. The speed is increased till vehicle achieves its limiting velocity on the circular path. The data is record continuously as long as the vehicle remains on the desired circular path with the corresponding correction in the steering wheel angle.

9 DATA ANALYSIS

9.1 General

The steady state values for all measured variables shall be established as their average values during any time interval of 1 s to 3 s during which steady state is maintained. For each selected time interval the limitations on path radius, steer angle, speed, rate of increase of lateral acceleration or throttle position specified in the description of the test procedure being followed shall be observed. In addition, for each selected time interval the standard deviation of lateral acceleration shall not exceed of its mean value. Refer to IS 17128 (Part 1) 'General conditions for M1 vehicles (**6.2.3**)'.

9.2 Lateral Acceleration

Theoretically steady state characteristics should be determined as functions of centripetal acceleration which is measured perpendicular to the path. Traditionally these characteristics have been expressed as functions of lateral acceleration which is measured perpendicular to the intermediate X-axis. At steady state, lateral acceleration and centripetal acceleration differ only by cosine of the side slip angle. In most cases, the vehicle side slip angle is small, so lateral acceleration may generally be considered to be equal to centripetal acceleration where large values of vehicle sideslip angle is observed or greater accuracy is desired, centripetal acceleration may be corrected to obtain lateral acceleration.

Steady state centripetal acceleration may be obtained by any one of the following three methods:

a) The product of yaw velocity and horizontal velocity:

$$Ay = (d\psi/dt)*v_x$$

b) The square of the horizontal velocity divided by the path radius:

$$Ay = v_x^2/R$$

c) The product of the square of the yaw velocity and the path radius:

$$Ay = (d\psi/dt)^2*R$$

The method used to determine lateral acceleration shall be noted in the test report.

10 DATA EVALUATION AND PRESENTATION OF RESULT

10.1 General

General data on the test vehicle shall be presented on a summary form using the general data test report contained in Annex A of IS 17128 (Part 1) .The general test conditions shall be presented using the test conditions test report contained in Annex B of IS 17128 (Part 1).

10.2 Plotted Results (Refer Annex A)

Measured data shall be plotted directly against lateral acceleration on figures, as follows:

a) Steering-wheel angle data points for the constant radius and constant speed test methods on Fig. A-1;
b) Path radius data points for the constant steering-wheel angle test method on Fig. A-2;
c) Side slip angle data points, if measured, on Fig. A-3;
d) Vehicle roll angle data points, if measured, on Fig. A-4; and
e) Steering-wheel torque data points, if measured, on Fig. A-5.

Curves may be fitted to the plotted points either freehand or by one of the many mathematical routines available. The method of curve fitting should be stated. This is particularly recommended where the process involves fitting smooth curves to experimental data for the purpose of evaluating the gradients. The type of curve and the method of fitting will influence the results obtained.

10.3 Evaluation of Characteristic Values

10.3.1 *General*

There are a number of ways to further process the data presented here. These have been developed as conventions over many years and each can be justified in its own way for example, the division of steering-wheel angle data by a nominal overall steering ratio. The following specified variables represent therefore, only examples for the evaluation of results, which describe vehicle steady-state behaviour. Any one of these methods may be used at the option of the user. If this evaluation is carried out it will be necessary to determine the overall steering ratio. The method for determining the overall steering ratio is given in Annex B.

10.3.2 *Evaluation of Gradients — Differentiation*

10.3.2.1 *General*

A common method of further treating basic experimental data is to derive the gradient of the curve fitted to the experimental points. The values of gradient thereby obtained are then plotted against the independent variable (in this case, lateral acceleration) to give a response graph.

As mentioned in **10.2** curves may be fitted to the experimental data either freehand or by a mathematical routine. If curve fitting is being done for the purpose of gradient evaluation, it is strongly recommended that the latter method be used otherwise, repeatability of resulting gradients cannot be guaranteed. In addition because each resulting curve will be described by a mathematical expression it can be differentiated mathematically to produce the gradient as a continuous function of lateral acceleration.

NOTE — It has been found that the characteristics of some vehicles have discontinuities in slope, which are not easily dealt with by standard curve fitting and differentiating techniques. By this means the following derived gradients can be obtained and plotted as functions of lateral acceleration. The gradients are plotted against lateral acceleration using the convention: lateral acceleration on the abscissa, with anti-clockwise positive, clockwise negative and the gradients on the ordinate with normal sign convention.

10.3.2.2 *Steering-wheel angle gradient*

This gradient is expressed by the following equation:

$$d(\delta_H) / d(A_Y)$$

The test is performed using only one steering-wheel angle.

10.3.2.3 *Path curvature gradient*

This gradient is expressed by the following equation:

$$d(1/R) / d(A_Y)$$

NOTE — This gradient cannot be computed from the results obtained using the constant-radius test method if the test is performed using only one turn radius.

10.3.2.4 *Sideslip angle gradient*

This gradient is expressed by the following equation:

$$d(\beta) / d(A_Y)$$

10.3.2.5 *Vehicle roll angle gradient*

This gradient is expressed by the following equation:

$$d(\varphi v) / d(A_Y)$$

10.3.2.6 *Steering-wheel torque gradient*

This gradient is expressed by the following equation:

$$d(M_H) / d(A_Y)$$

10.3.2.7 *Steering-Wheel/Sideslip Angle Gradient*

This gradient is expressed by the following equation:

$$d(\delta_H) / d(\beta)$$

While, in theory the steering-wheel/sideslip angle curve can be produced from ratio of curves of steering wheel angle and sideslip angle *versus* lateral acceleration, this method is likely to lead significant errors. It is preferable to fit a curve directly to the steering-wheel angle *versus* sideslip angle data and to differentiate it with respect to sideslip angle to produce steering-wheel/sideslip angle gradient *versus* sideslip angle, and then to transform the latter variable into lateral acceleration by using the sideslip angle/lateral acceleration relationship given in **10.3.2.4**.

NOTES:

1 This curve is believed by some experts to relate strongly to the vehicle behaviour as perceived by the driver, that is, the relationship between the steering-wheel input and the resulting vehicle sideslip angle.

2 This gradient cannot be computed from the results obtained using the constant steering-wheel angle test method if the test is performed using only one steering-wheel angle.

10.3.3 *Normalisation of Results Comparison of Results from Different Vehicles*

10.3.3.1 *General*

Gradients obtained by different methods at a given steady state equilibrium condition may differ. This is because different test methods control lateral acceleration by different variables (speed, path radius or steering wheel angle). Therefore, only data obtained by the same method and at the same speed and radius steady state conditions are comparable.

10.3.3.2 *Explanation*

In any general case of a vehicle making a steady state turn of given radius, the steer angle required will consist of two parts: that due to the ackermann effect, which is for a given radius is proportional to the wheelbase and that due to handling characteristics of vehicle. In addition, steering-wheel angle corresponding to required steer angle will depend on overall steering ratio.

Thus, there are three quantities to be taken into account in the general case:

a) Wheelbase,
b) Overall steering ratio, and
c) Steering-wheel angle gradient.

The units of the steering-wheel angle gradient will be degree per metre per second square, and by convention a vehicle with zero steering-wheel angle gradient that is, to say one which needs no movement of its steering wheel when changing speed on a curve of constant radius is defined as a neutral steer vehicle. The steering-wheel angle of a neutral steer vehicle becomes a function only of turn radius, steering ratio and wheelbase. The steering-wheel angle gradient of any vehicle can be normalised by dividing the measured responses of actual vehicle by product of its wheelbase and steering ratio. The practical benefits of doing this are that the steering-wheel angle gradient of vehicles of widely different sizes and steering ratios can be compared analytically by comparing their normalized measured responses.

Comparison of measurements that have not been normalised will not clearly show differences in steering-wheel angle gradient because they also contain the effects of differences in wheelbase and steering ratio.

In this particular procedure the numerical value of the product of wheelbase and steering ratio is the same as the product of the test radius and the steering-wheel angle in radians, required at zero speed on that radius.

This steering-wheel angle is the intercept of the curve in Fig. A-1 with the zero lateral acceleration line and thus, the value of the product of steering ratio and wheelbase can be obtained without direct measurement.

10.3.4 *Normalized Steady-State Properties*

10.3.4.1 *General*

In the light of the explanation given in **10.3.3.2** it is now possible to define normalized steady-state properties that correspond to the non-normalized ones of **10.3.2**. However, there does not appear to be any significance in normalized sideslip angle, roll angle or torque gradients and therefore only normalized equivalents of steering wheel/ sideslip angle gradient are described.

10.3.4.2 *Normalization with respect to steering ratio*

This technique is useful for comparing results from vehicles of similar wheelbase. The procedure for measuring steering ratio is given in Annex B.

a) Understeer gradient:

   This gradient is determined by dividing the steering-wheel angle gradient by the steering ratio and subtracting the dynamic reference steer angle gradient:

$$((d(\delta_H) / d(A_Y)) / (i)) - (d(\delta_D) / d(A_Y))$$

   In a constant-radius test (*see* **8.4**), the dynamic reference steer angle gradient is zero, so the equation can be written as:

$$(d(\delta_H) / d(A_Y)) / (i_s)$$

   Whereas, in a constant steering-wheel angle test (*see* **8.5**), the steering-wheel angle gradient is not defined, and understeer can be found most directly from the path curvature gradient (*see* **10.3.2.3**) as the product of the wheelbase and the path curvature gradient:

$$l * (d(1/R) / d(A_Y))$$

b) Understeer/sideslip gradient:

   This gradient is determined by dividing the steering-wheel/sideslip angle gradient (*see* **10.3.2.7**), by the steering ratio:

$$(d(\delta_H) / d(\beta)) * (1/i_s)$$

10.3.4.3 *Normalization with respect to wheelbase — Stability factor*

This technique yields response values that can be used to compare vehicles of widely different sizes. The stability factor is determined by dividing the understeer gradient by the wheelbase.

10.3.4.4 *Normalization with respect to sideslip angle gradient — Directional coefficient*

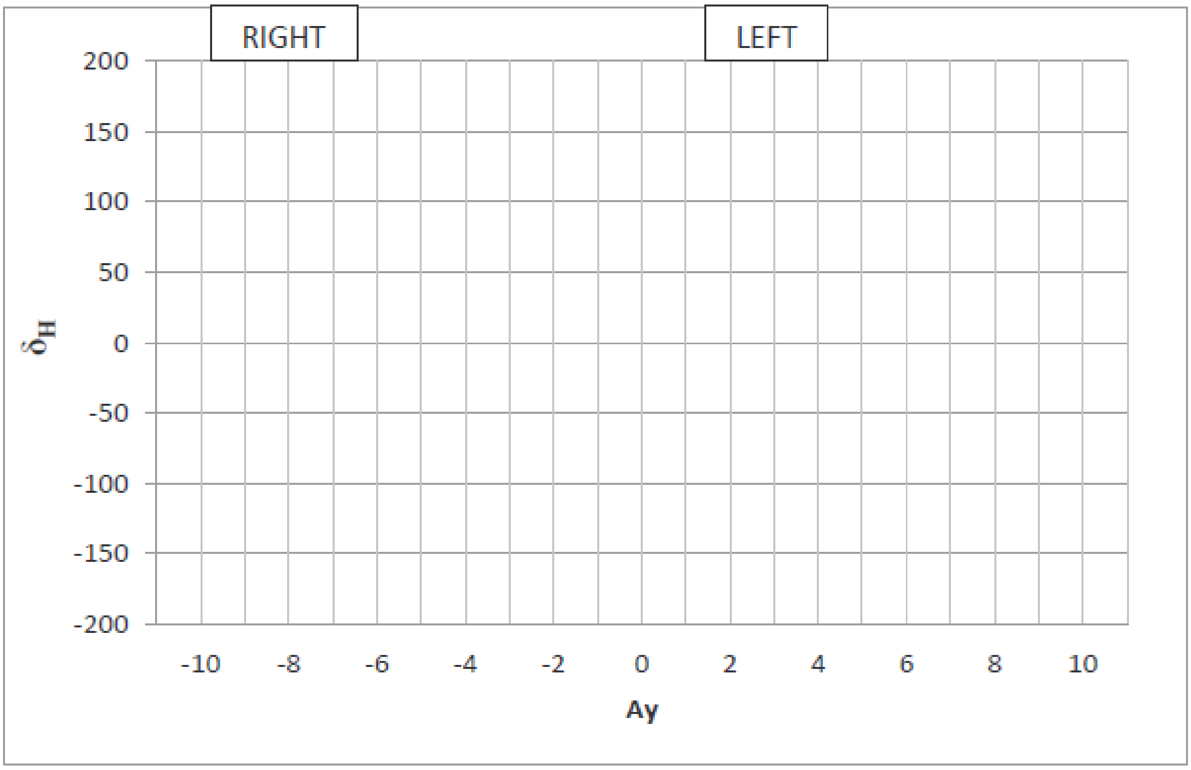
The directional coefficient is determined by dividing the stability factor by the sideslip angle gradient.

ANNEX A

(*Normative*)

PRESENTATION OF RESULTS

A-1 The characteristic values of the vehicle dynamic reaction shall be presented as functions of steady-state lateral acceleration in accordance with Fig. 1 to 5.



Vehicle: ....

Turn radius (constant-radius test method): ....

Test speed (constant-speed test method): ....

Key

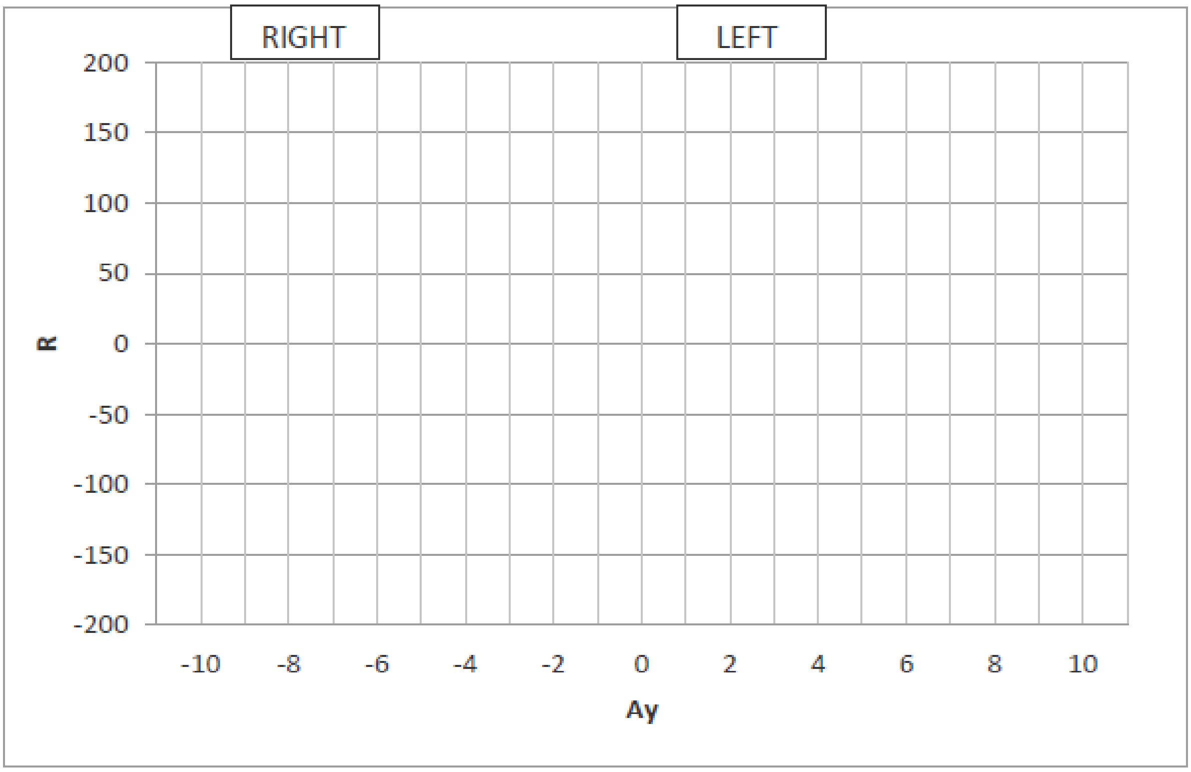
Ay - lateral acceleration, m/s^2

δ_H - steering-wheel angle, degrees

RIGHT - right turn

LEFT - left turn

FIG. 1 STEERING-WHEEL ANGLE CHARACTERISTIC



Vehicle: ....

Steering-wheel angle (constant steering-wheel angle test method): ....

Key

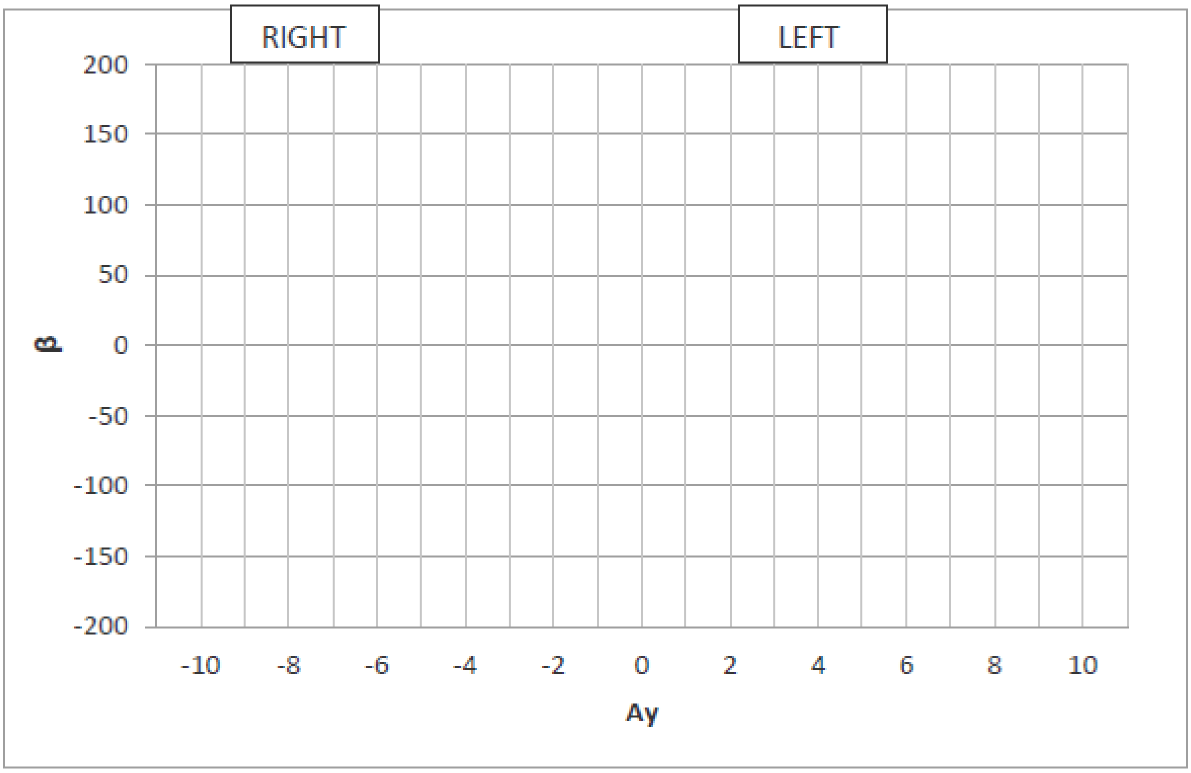
Ay - lateral acceleration, m/s^2

R - path radius, m

RIGHT - right turn

LEFT - left turn

FIG. 2 PATH RADIUS CHARACTERISTIC

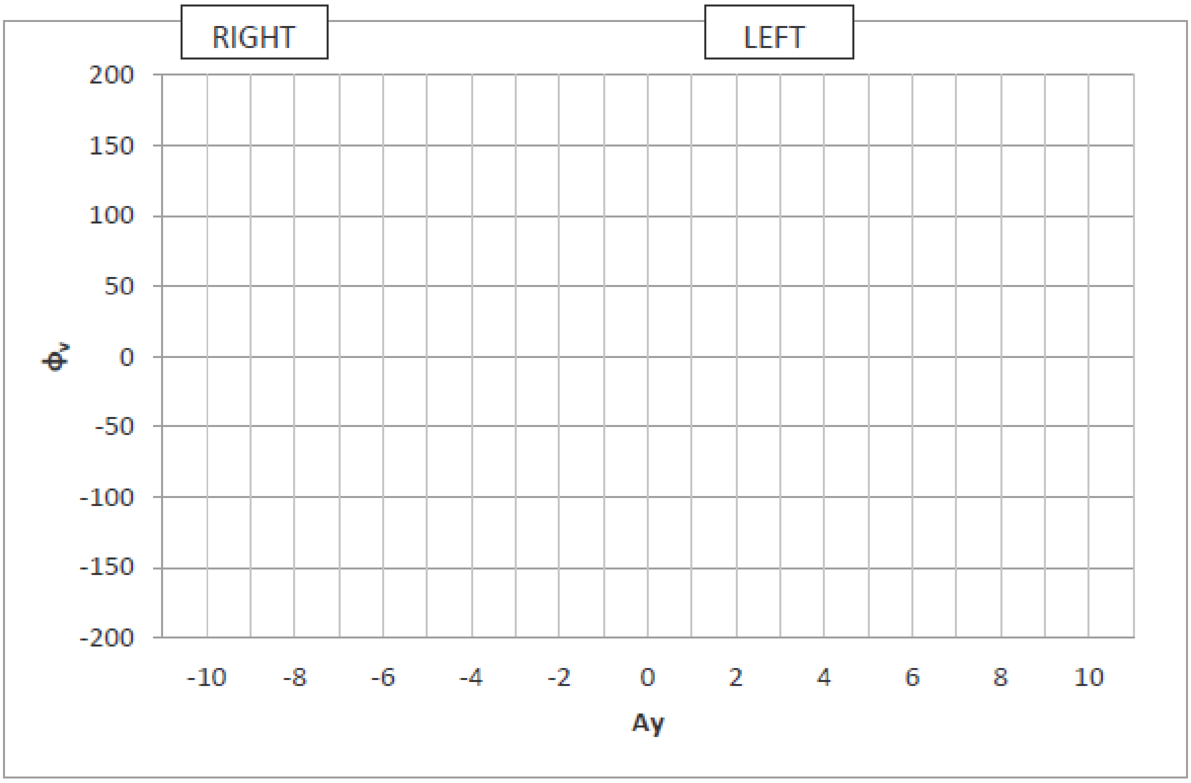


Vehicle: ....
Turn radius (constant-radius test method): ....
Steering-wheel angle (constant steering-wheel angle test method): ....
Test speed (constant-speed test method): ....

Key

Ay - lateral acceleration, m/s^2
β - sideslip angle, degrees
RIGHT - right turn
LEFT - left turn

FIG. 3 SIDESLIP ANGLE CHARACTERISTIC



Vehicle: ....

Turn radius (constant-radius test method): ....

Steering-wheel angle (constant steering-wheel angle test method): ....

Test speed (constant-speed test method): ....

Key

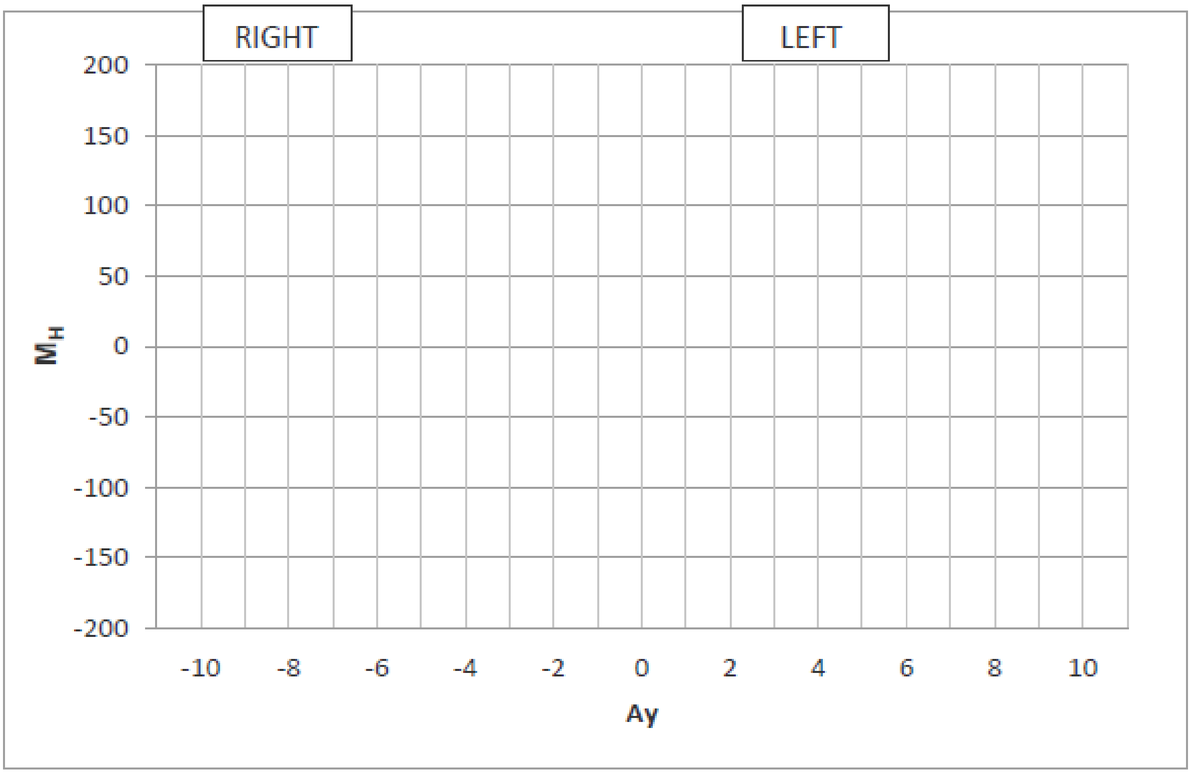
Ay - lateral acceleration, m/s^2

φ_v - vehicle roll angle, degrees

RIGHT - right turn

LEFT - left turn

FIG. 4 VEHICLE ROLL ANGLE CHARACTERISTIC



Vehicle: ....

Turn radius (constant-radius test method): ....

Steering-wheel angle (constant steering-wheel angle test method): ....

Test speed (constant-speed test method): ....

Key

Ay - lateral acceleration, m/s^2

M_{H} - steering-wheel torque, Nm

RIGHT - right turn

LEFT - left turn

FIG. 5 STEERING-WHEEL TORQUE CHARACTERISTIC

ANNEX B

(*Normative*)

DETERMINATION OF OVERALL (STATIC) STEERING RATIO

B-1 STEERING SYSTEMS

Understeer gradients are stated in terms of the difference in cornering compliances between the front and rear road-wheel ‘axles’. However, cornering compliances include deflections of the steering system due to elastic deformations. In order to include steering-system compliances, understeer is determined from measurements taken at the steering wheel. Steering-wheel angles are referred to the road wheels by the overall steering ratio.

Overall steering ratio is a variable which describes the geometric relationship between steering-wheel angle and average road-wheel angle, measured under conditions of zero aligning moment and lateral force. If the steering system is significantly non-linear, each measured steering-wheel angle must be used together with a plot of average road-wheel angle versus steering-wheel angle to obtain the corresponding road-wheel steer angle. Steer angle gradients are obtained from a plot of road-wheel steer angle versus lateral acceleration.

B-2 VEHICLES WITH FOUR-WHEEL STEERING

Current four-wheel steering systems can be divided into three general types: rear steer having a programmed relationship to steering-wheel angle; rear steer programmed according to lateral acceleration; and rear/front steer ratio programmed according to speed or other, more complex, relationships. The first type creates a combined net-effect front/rear steering ratio, which is in general non-linear. The second type can be treated as only an additional source of (usually negative) rear wheel compliance steer. However, the third type must be considered as a separate control input. For steady-state testing of this third type of vehicle it could be necessary to disable the rear steering so as to measure basic response parameters, then by additional testing with rear steer enabled, determine the rear-steer control algorithm, and measure its effect on steady-state response parameters. Alternatively, tests of vehicles with systems of the third type may be conducted by holding the state that affects the rear steer ratio constant during the test. For example, vehicles with a speed-varying rear steer ratio may be tested using the constant-speed test method. Repeat tests at several different speeds would define the vehicle characteristics at different operating conditions.

B-3 MEASUREMENT

The overall steering ratio shall be determined for each vehicle test configuration over the range of steering wheel angles used during the test.

The overall steering ratio will not, in general, represent the dynamic situation because of additional steering system deflections caused by compliance and geometric effects. It is, however, suitable for removing the effect of different steering-system lever and gear ratios from comparisons of measurements from different vehicles.

The compliance and geometric effects referred to above are then quite properly regarded as part of the vehicle handling characteristics.

ANNEX C

(*Informative*)

GENERAL INFORMATION — THEORETICAL BASIS FOR THE TEST METHODS

C-1 The path curvature of an automobile in steady-state turning at a given speed (that is, in a given state of steady-state equilibrium) is determined by speed, steering-wheel angle, wheelbase, and the elastic and kinematic characteristics of the front and rear steering systems, suspensions and tyres.

In the absence of kinematic and compliance steer effects; for example, at very low speeds, the low-speed path radius is defined geometrically by wheelbase and by front- and rear-wheel steer angles. At increasing speed, steady-state turning results in centrifugal force, which produces kinematic and compliance steer and camber. When expressed in degrees per meter per second squared of lateral acceleration and lumped together, these “cornering compliances” produce steer angles and tyre slip angles in front and rear that modify the low speed path radius. Cornering compliances subtract from the front and rear Ackermann steer angles. Cornering compliances greater in the front than in the rear increase path radius from the Ackermann condition, and produce under steer; while cornering compliances greater in the rear than in the front reduce path radius, causing over steer. The difference between the total front and rear cornering compliance is called the under steer gradient, expressed in degrees per meter per second squared. Similarly, the change in steering-wheel angle required to maintain a given radius with increasing lateral acceleration is called steering-wheel angle gradient, the change in roll angle with lateral acceleration is called roll angle gradient, etc.

The test procedures specified by this International Standard are designed to be used to measure these various vehicle steady-state properties. The sensitivities of the vehicle’s responses to steering wheel inputs are called yaw velocity gain (degree per second per degree of steering-wheel movement), lateral acceleration gain (meters per second squared per degree of steering-wheel motion), sideslip gain, etc. These can be calculated from the vehicle speed, steering wheel angle, steering ratio, wheelbase and under steer gradient, or they can be obtained directly from measured data.

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